NEUTRON PRODUCTION MEASUREMENTS FROM SHIELD MATERIALS

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Astronauts who spend months and years traveling long distances in spacecraft and working on other planets will be subjected to high-energy radiation of galactic and solar origin without the protection of the Earth's thick (one writer has called it buff) atmosphere and magnetic field. The lack of natural protection will allow high-energy cosmic ray particles and solar protons to crash directly into relatively thin spacecraft walls and planetary atmospheres producing energetic secondary particles in these collisions.

A substantial fraction of these secondaries will be neutrons that carry no electric charge and, consequently, are difficult to detect. At sea level on Earth the remaining neutrons are the result of many generations of collisions producing a spectrum with a large low energy component. These neutrons do contribute to the natural background radiation dose seen by humans amounting to hundreds of millirems per year.

In the International Space Station or on the surface of Mars, the secondary neutrons will be the result of only one or two generations of interaction due to the thinner (about a factor of 20 compared to the Earth's atmosphere) walls or atmosphere, have considerably more energy and penetrate deeply into the human body. In addition, neutrons are substantially moderated by hydrogenous material such as water. A significant fraction of the water exists in the astronaut's body. Therefore, the neutron can not only penetrate more deeply into the body, but also be stopped there and deposit all or a significant fraction of its energy as radiation dose in organs such as the liver, spleen, kidney, etc. We hypothesize that the risk of serious cancers will be increased for the exposed humans.

The portable, real time neutron spectrometer being developed by our team will monitor the environment inside spacecraft structures and on planetary surfaces. Activities supported by this grant will evaluate the neutron environment behind candidate spacecraft materials at accelerator facilities. These experiments will enable engineers to choose the structure materials that minimize the production of secondary neutrons. With the information that the neutron energy spectrometer produces, scientists and doctors will be able to assess the increased risk of cancer and develop countermeasures.

A 5 mm thick lithium drifted silicon detector system for an engineering prototype spectrometer funded by NASA/NSBRI has been tested and calibrated with mono-energetic neutron beams at the Los Alamos Neutron Science Center (LANSCE) and the Columbia University Radiological Accelerator Research Facility (RARAF). While at LANSCE we also conducted experiments on the effectiveness of polyethylene in shielding high-energy neutrons. A prototype spectrometer consisting of the thick silicon detector for high energy neutrons and a helium 3 gas tube detector for low energy neutrons was flown at 40,000 feet altitude in fighter aircraft from NASA Dryden in 2001 as an engineering test to verify flight capability.

Keywords: neutrons, shielding, thick target collisions, radiation

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Balloon flights are planned for 2002 and 2003 at altitudes that should yield downward high-energy neutron spectra similar to those to be experienced on the surface of Mars.

For ground based neutron shielding materials studies at proton and heavy ion beam accelerators we modified the proto-flight spectrometer to use a thin silicon transmission detector in the beam direction as a charged particle veto instead of the bulky CsI tube that surrounds the thick silicon detector to be used in flight. The primary purpose of the instrument is to determine the neutron spectrum produced behind shielding material due to nuclear reactions between the incident particle beam and the shielding material. This task is accomplished by recording the non-vetoed neutron energy deposition events in the thick Lithium Drifted Silicon (SiLi) detector and using a response function inversion method to de-convolve the most probable incident neutron spectrum. The block diagram of this detector system is shown in Figure 1. The construction of this instrument dedicated to accelerator facility testing has been completed. An aluminum mounting frame to hold and position the detector system has also been fabricated. The detector system can be placed behind the shielding material at various distances near the beam axis and at small angles in the forward direction off the beam axis.

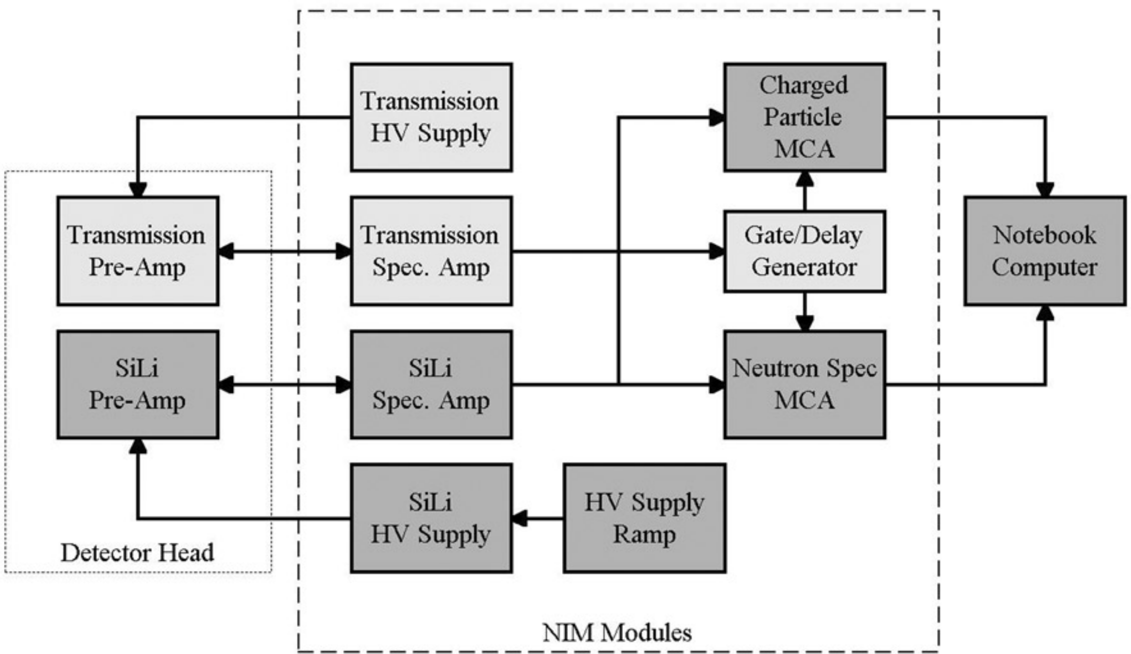

Figure 1: Shielding Materials Experimental Configuration showing the transmission and bulk solid state detectors mounted in tandem. The front transmission detector provides charged particle anticoincidence in the beam direction only.

Experimental characterization of this detector system with respect to its neutron detection efficiency and ability to discriminate against charged particles including calibration has been completed at Columbia RARAF and the results are shown in Figure 2. The smaller accelerator system gives results equivalent to those of the bulkier flight system.

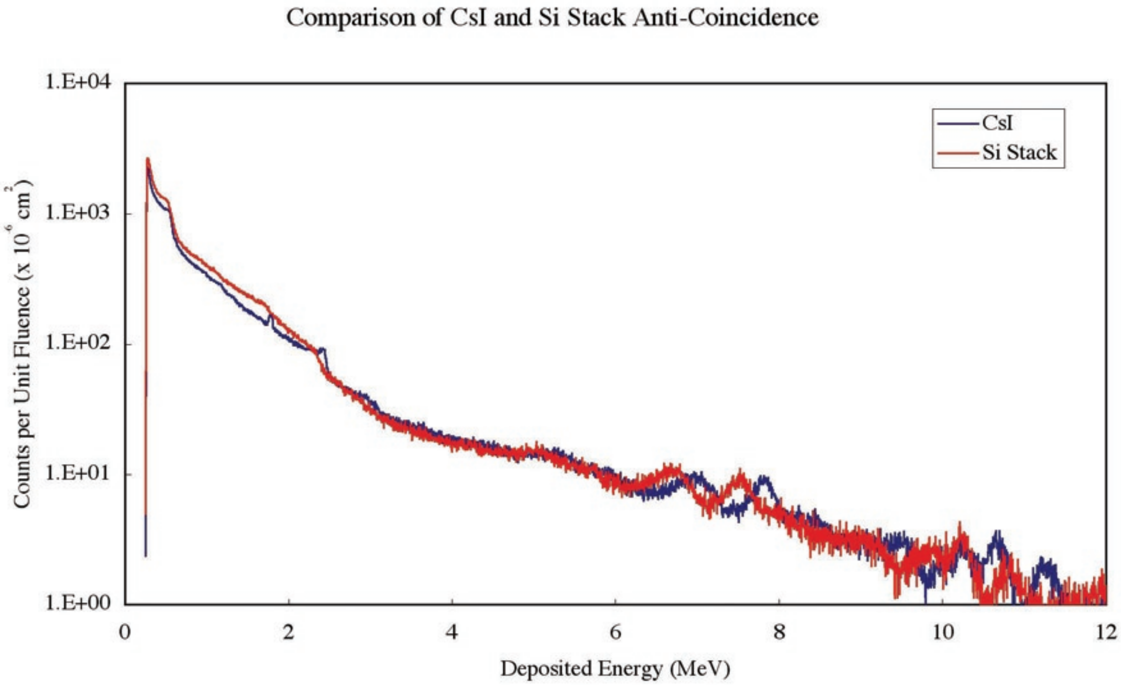

Figure 2: Comparison of CsI scintillator and silicon transmission anti-coincidence detectors and the counts per unit 14 MeV neutron fluence at Columbia RARAF. This comparison shows that the smaller detector system in Figure 1 gives the same results for neutron energy deposition spectra when the beam and anti-coincidence are unidirectional.

From the experiments at RARAF with 14 MeV neutrons and five shield thicknesses of polyethylene we have deduced the integral energy deposition spectra shown in Figure 3. The mostly parallel set of curves indicate that one needs 4”, 2” of polyethylene to reduce the 7 MeV (half the incident neutron energy) depositions by factors of 3, 1.8 respectively. The results for energy depositions of 2 MeV are very similar. For polyethylene thicknesses of 1” or less the greatest reduction in neutron depositions is about 25%.

Similar results were obtained at LANSCE for 20-600 MeV neutrons as shown in Figure 4. In this case almost no reduction in neutron flux occurred for 2” of polyethylene and 4” was necessary to achieve a significant reduction (~a factor of 4.5).

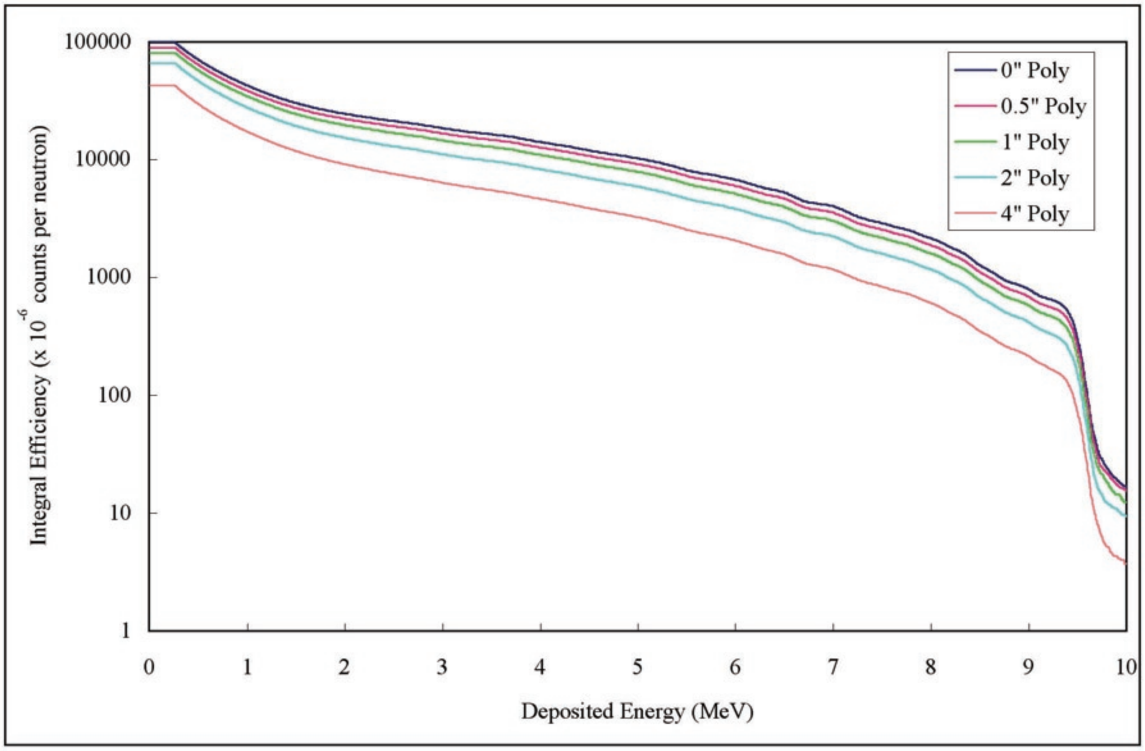

Figure 3: Integral Response Deposition Spectra due to 14 MeV neutrons incident on Polyethylene. The ordinate axis has been multiplied by 10^6 to make the exponents positive. From top to bottom the curves are for 0, 0.5, 1, 2, 4 inches of polyethylene.

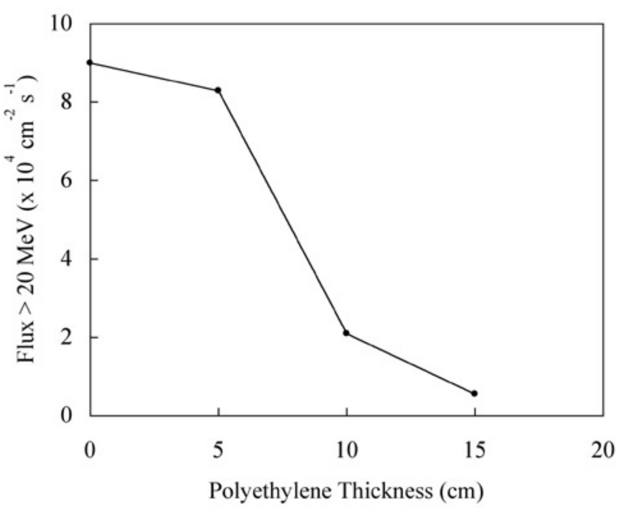

Figure 4: Polyethylene Shielding Effectiveness for High Energy Neutrons. The ordinate scale is integral flux > 20 MeV in units of cm^{-2} sec^{-1}

Summary:

1) We have designed and fabricated a stack detector system consisting of a silicon transmission detector and a 5mm thick lithium drifted silicon detector. This system has the same charged particle anti-coincidence efficiency in the accelerator beam direction as our flight prototype has from a CsI crystal surrounding a thick lithium drifted detector as shown by experiments with 14 MeV neutrons. This system is available for radiation shielding material experiments.
2) From work supported by the National Space Biomedical Research Institute (NSBRI) we have developed and verified a de-convolution technique that calculates a most probable incident neutron energy spectrum from the deposited energy spectra measured by the 5mm thick silicon detector. A publication on this result is presently in the review cycle.
3) We find for fast and high-energy neutrons that four inches (10 cm) of polyethylene is necessary to make a significant reduction in the neutron flux. For the fast (10-20 MeV) neutrons a reduction of a factor of 3 was indicated while for the high-energy neutrons (20-600 MeV) a factor of 4.5 was determined.
4) We are planning to study neutrons produced in collisions of high-energy protons with prospective shield materials in the Fall of 2002. We will measure both the neutron spectra produced in these collisions and the shielding effectiveness of polyethylene for these same spectra.